A Global Survey of ELF/VLF Radio Noise

Antony Fraser-Smith
Space, Telecommunications and Radioscience Laboratory
Stanford University
Stanford, CA 94305-9515
phone: (650) 723-3684 fax: (650) 723-9251 email: acfs@alpha.stanford.edu

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LONG-TERM GOAL

The specific long-term goal of this project is to provide the Navy with greatly improved information about the characteristics of both natural and man-made radio noise and signals in the ELF/VLF bands (frequencies in the range 10 Hz to 32 kHz), with the object of improving the Navy's ELF/VLF radio communications.

SCIENTIFIC OBJECTIVES

The project has two related scientific objectives. The first objective is to improve knowledge of the sources of radio noise in the ELF/VLF band; the second is to improve knowledge of the propagation of ELF/VLF radio noise and man-made signals in the earth's environment, i.e., in the earth-ionosphere waveguide, in the magnetosphere, in the sea, and in the earth's crust.

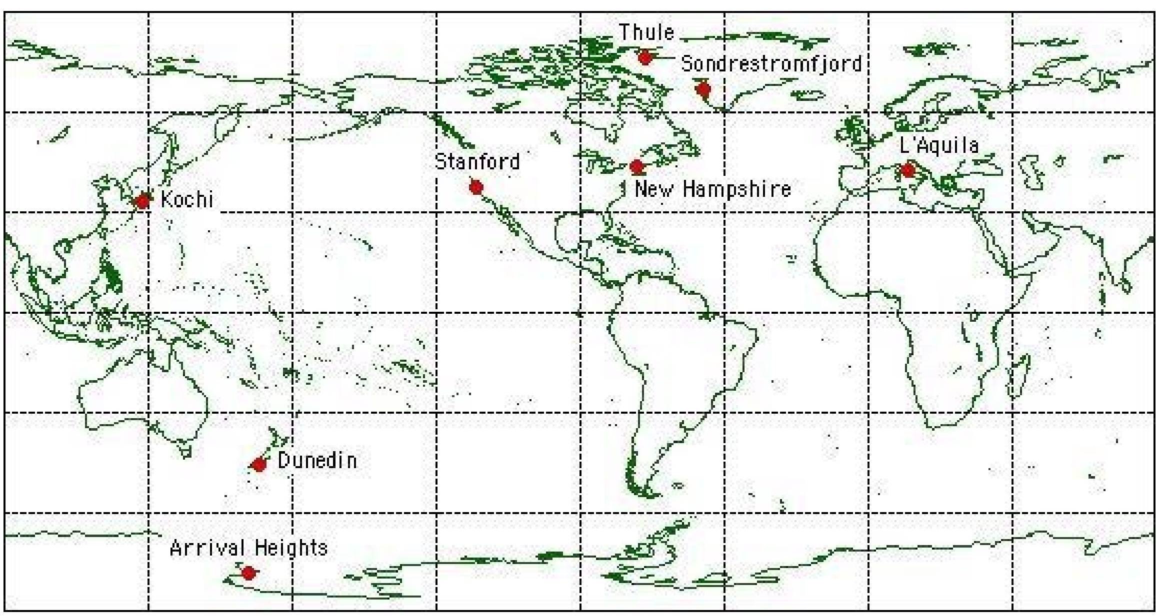

Figure 1: Locations of the eight original ELF/VLF radiometer installations. Only the Stanford, Sondrestromfjord and Arrival Heights radiometers are currently being maintained in continuous operation.

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14. ABSTRACT
The specific long-term goal of this project is to provide the Navy with greatly improved information about the characteristics of both natural and man-made radio noise and signals in the ELF/VLF bands (frequencies in the range 10 Hz to 32 kHz), with the object of improving the Navy’s ELF/VLF radio communications.

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APPROACH

An important feature of the project since its commencement has been its heavy emphasis on measurement, starting (in 1985) with the installation of eight ELF/VLF radio noise measurement systems around the world, including high (polar) latitudes (Figure 1; Figures 2 and 3 show the antennas that are used). When in operation, each of these systems continuously computes the following radio noise statistics: the root-mean-square (rms), average, maximum, and minimum amplitude of the noise in 16 narrow frequency bands (5% bandwidth) distributed through the range 10 Hz to 32 kHz. The noise statistics are computed at the end of every minute from 600 amplitude measurements made at the rate of 10 per second on the envelope of the noise signal emerging from each narrow-band filter. Later processing of these data can, with little additional computation, give the V_d and Fa statistics, and amplitude probability distributions (APDs) are also readily derived from the sampled data. These data are recorded on digital magnetic tape and shipped back to Stanford University, where they are analyzed.

In addition to the data from the narrow-band filters described above, broad-band ELF digital data (~1 – 400 Hz), sampled at a rate of 1000 samples per second during one minute each hour, are also recorded on the digital tape. These data can be quickly processed to give spectrograms, which provide an essential check on the quality of the narrow-band digital measurements in the ELF range. A similar broad-band picture of activity in the overall ELF/VLF range is provided by simultaneous one-minute analog recordings of the radio noise in the range ~200 Hz to 32 kHz. These broad-band data can be processed to provide further noise statistics. For example, statistical analyses of the time between noise pulses can be quickly computed. The data are also an invaluable resource for further research. To illustrate, they have enabled quantitative studies to be made of the variation of APDs with the bandwidth of the measurements, and they have enabled us to carry out the first tests using real experimental data, of theoretically-derived probability density functions for ELF/VLF radio noise.

Because the principal source of ELF/VLF radio noise is the lightning occurring in thunderstorms around the world, our noise measurements relate closely to global weather and thus they are capable of providing independent and, as it turns out, entirely new information on two topics of great current relevance: global climate change (or global warming) and possible sun-weather relations.

The value of our measurements at Arrival Heights has been recognized by the Office of Polar Programs of the National Science Foundation, which has provided all the logistical support for the Antarctic station since it was first installed. The continued operation of the station has been subject to NSF/OPP's usual peer review process, and our measurement program has always been rated excellent. The OPP recently renewed its logistical support in 2001 for a further four-year interval.

Following the receipt of a DoD instrumentation grant in 2001 (ONR Grant N00014-01-1-0543), we are currently upgrading our operational radiometers (1) to use GPS timing, and (2) to record their ELF/VLF data on DVD disks instead of on magnetic tape. These important changes have necessitated a change in the computers installed in the radiometers and the rewriting of all the system software. At the time of writing (October 2002) the Sondrestromfjord system has been completely upgraded and the Stanford and Arrival Heights upgrades are in progress.

WORK COMPLETED

We have built up an extensive database of ELF/VLF noise measurements extending back to 1985 and it is probably true to say that there is no comparable database of low-frequency radio noise measurements available elsewhere. Since most of our original data acquisition goals have been achieved, only three of the original eight ELF/VLF radio noise measurement systems installed around the world at the start of this project are currently being maintained in continuous operation (Stanford, USA, Sondrestromfjord, Greenland, and Arrival Heights, Antarctica (see Figure 1)); four others (Kochi, Japan; Dunedin, New Zealand; Grafton, New Hampshire; Thule, Greenland) remain in place and are operated intermittently during particular short-term measurement programs. The Stanford and Arrival Heights radiometer measurements continue to extend what are now two uniquely lengthy collections of ELF/VLF noise data.

Figure 2. The VLF antennas for the Stanford University radiometer; they are installed in a remote section of the campus. The ploughed area in the foreground is a firebreak.

Figure 3. The two ELF antennas (the blue coils) used in the Stanford radiometers. In practice they are covered by a wooden (non-magnetic) windshield structure.

Over the last few years the Stanford radiometer group has carried out a number of extensive analyses of the ELF/VLF data to obtain new information on subjects as diverse as (1) the diurnal and seasonal variations of the noise, (2) the locations of the principal sources of ELF noise around the world, (3) how global change might be reflected in changes in global lightning and thunderstorm activity, and (4) the best theoretical models describing ELF/VLF noise. In addition, a first experimental test of the theory of propagation of ELF radio waves at large distances from the source was carried out using measurements on signals from a Russian ELF (82 Hz) transmitter.

RESULTS

Our work on lightning and related phenomena generating radio signals at low-frequencies has led to several new observations: In 1998 we reported how we had quantified, for the first time, the characteristics of sprite-associated ultra-low frequency (ULF; frequencies less than 5 Hz) waveforms observed in California at a distance of about 1900 km to the west of the sprite-producing thunderstorms, and we introduced the term "ultra-slow tails" for these unusual waveforms [*Füllekrug, Fraser-Smith, and Reising*, 1998]. In 1999, by comparing our ELF measurements with a collection of electric field measurements made at the south pole by E. A. Bering, we were able to estimate the contribution of global lightning to the global electric circuit – the circuit that maintains a roughly 100 V/m vertical electric field in fair weather regions around the world. Our analysis suggests that lightning can only account for about 50% of the global electric field. The subject is controversial, but the data and our interpretation have now been published [*Füllekrug, Fraser-Smith, Bering, and Few,* 1999]. Further extensions of this work in the ELF range have enabled us (1) to comment on a connection between Schumann resonances (7–40 Hz) and convection phenomena in global weather [*Anyamba et al.,* 2000] and (2) to

carry out long-term monitoring of the height of the ionospheric D-layer [*Füllekrug, Fraser-Smith, and Schlegel*, 2002].

In 1998 a graduate student, D. A. Chrissan, completed his Ph.D. research on the statistical properties and modeling of ELF/VLF radio noise and on improvements in low-frequency radio communications. His dissertation was completed in August 1998 and it was converted into a final technical report [*Chrissan*, 1998]. The APD results presented in this dissertation are particularly important in communications and we expanded upon them in a paper that was published in 2002 [*Chrissan and Fraser-Smith*, 2000]. The principal theoretical result of the dissertation, a clustering Poisson model for characterizing the interarrival times of ELF/VLF sferics, has now been described in a paper that will shortly be published [*Chrissan and Fraser-Smith*, 2002].

Finally, our participation in one of the HAARP experimental programs, during which we made much use of the ELF/VLF radio noise data being measured routinely by our Stanford ELF/VLF radiometer, resulted in a number of unusual observations of both natural and man-made ELF/VLF noise [*Porrat, Teague, and Fraser-Smith*, 1999]. Our objective was to make the first long-distance detection of ELF signals generated by the HAARP ionospheric heater; we did not succeed, but the continuing improvements to the HAARP heating facility in Alaska will ultimately lead to the routine generation of ELF/VLF signals at ranges useful for strategic communications. Some features of the earlier experimental observations have now been described in a paper by *Porrat, Bannister, and Fraser-Smith* [2001]. We believe this is the first time that the modal properties of lower-ELF radio wave propagation in the Earth-ionosphere waveguide have been so clearly demonstrated. This latter work on ELF radio propagation stimulated an encyclopedia article on radio propagation at ELF [*Porrat and Fraser-Smith*, 2001].

IMPACT/APPLICATIONS

The measurements we have made of the seasonal variations and other statistical properties of ELF/VLF noise are the first statistically robust measurements available to Navy communicators. Our most recent work specifically describes improvements to low-frequency radio communications that should result from our analyses and modeling [*Chrissan*, 1998; *Chrissan and Fraser-Smith*, 2000; *Chrissan and Fraser-Smith*, 2002] and it provides what is undoubtedly the most comprehensive description of the operationally-important APD statistics for ELF/VLF noise as well as a detailed model of the clustering that occurs in ELF/VLF sferic occurrences.

Our measurements indicating that lightning can only account for about 50% of the global electric field are controversial, as we have indicated. We suspect they will stimulate more work on the fair weather electric field that we are all exposed to and which, under less than fair conditions, leads to unusual electrical phenomena (such as St. Elmo’s Fire) on Navy vessels.

TRANSITIONS

As we have indicated above, our ELF/VLF measurements provide new information that is directly and importantly relevant to Navy strategic communication studies.

RELATED PROJECTS

Studies of global change are becoming increasingly important. As we have noted above, our ELF/VLF measurements relate to lightning and thunderstorm activity in the tropical regions – as well as North America. We can therefore claim that our work relates to many current projects that involve studies of global warming/global change and our analyses can provide new information on this important topic.

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